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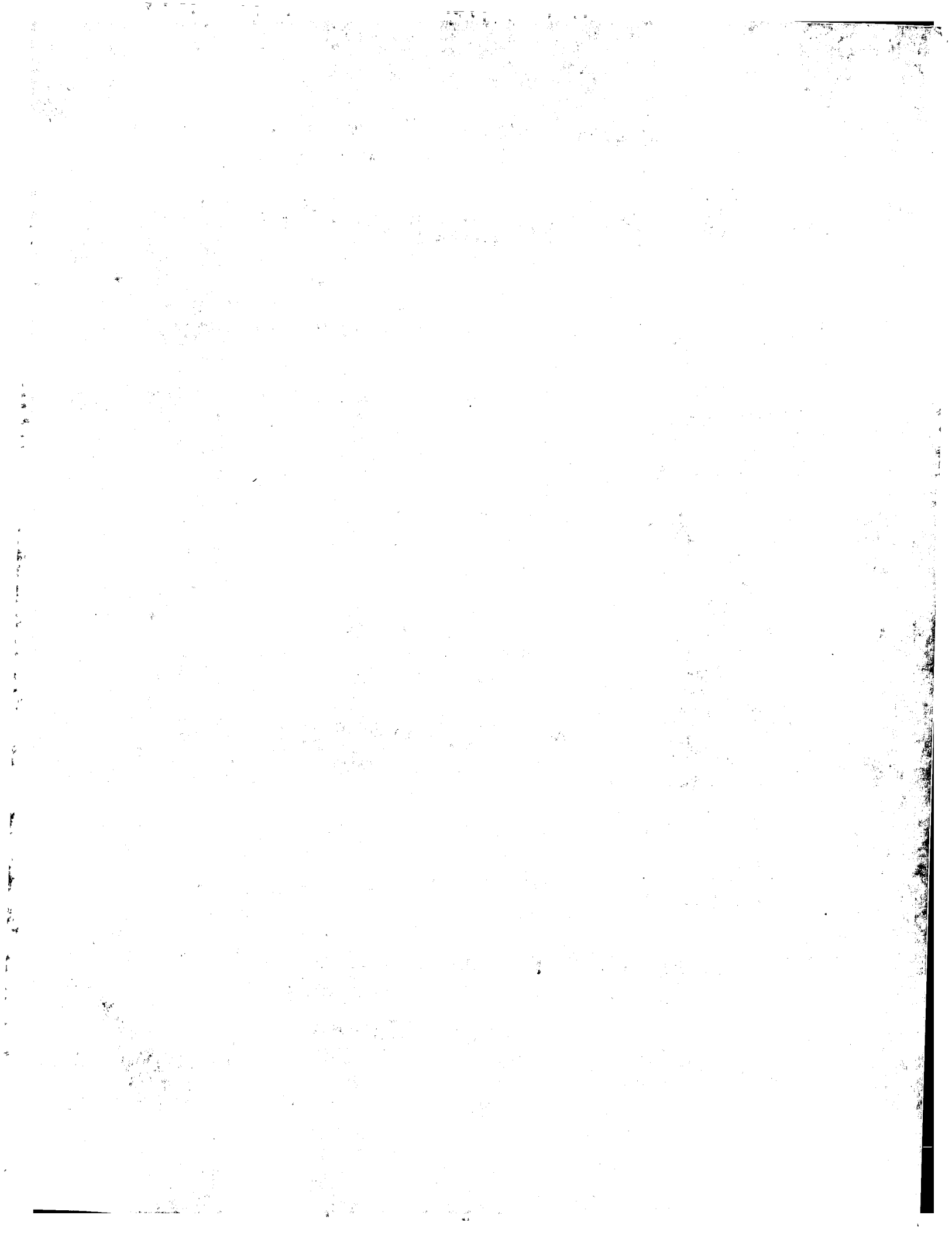
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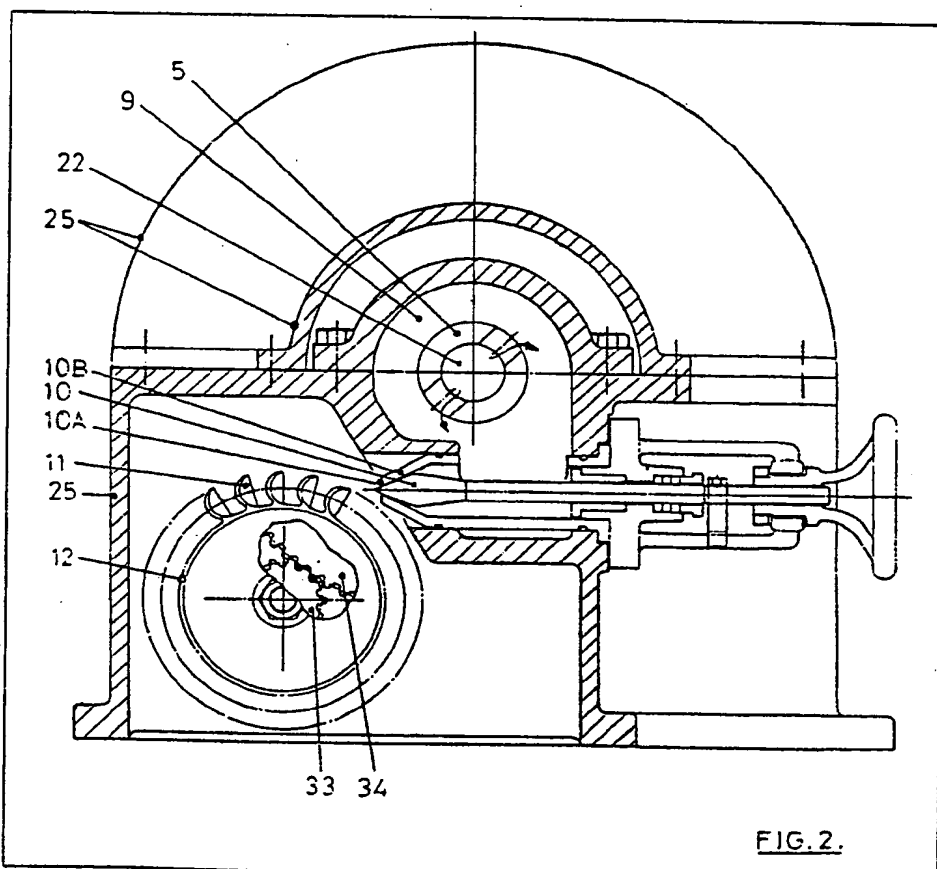
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(71) Applicant
Michael Leslie Ryall
Little Caldon
18 Drumbeg Loan
Killearn G63 9LG
(72) Inventor
Michael Leslie Ryall
(74) Agent and/or Address for
Service
Fitzpatricks
4 West Regent Street
Glasgow G2 1RS

(54) Variable speed transmission including fluid pumping means

(57) A variable speed transmission for coupling a constant speed driver to a variable speed load includes a rotary input shaft and a rotary output shaft (5) linked by a fluid drive means including a pump. Broadly, the pump includes rotor means coupled to the input shaft and a rotatable pump casing drivingly connected with the output shaft, a valve (10) being provided in the discharge from the pump. The rotor means may constitute meshing sun/planet gears (Fig. 3) where the pump is a gear pump, or may include vanes (45) engaging a loaded casing (49) when the pump is a vane pump (Fig. 6). At start up the valve (10) is open and pressurised fluid is discharged from the pump; and the output shaft (5) rotates at a

low speed. At normal operation, the valve (10) is closed and the pump is effectively fluidly locked so that output speed substantially equals input speed. The pump pressure fluid discharge can be fed to a motor e.g. a turbine (11) drivingly connected to the output shaft (5) so that there can be energy regain at reduced speed operation.



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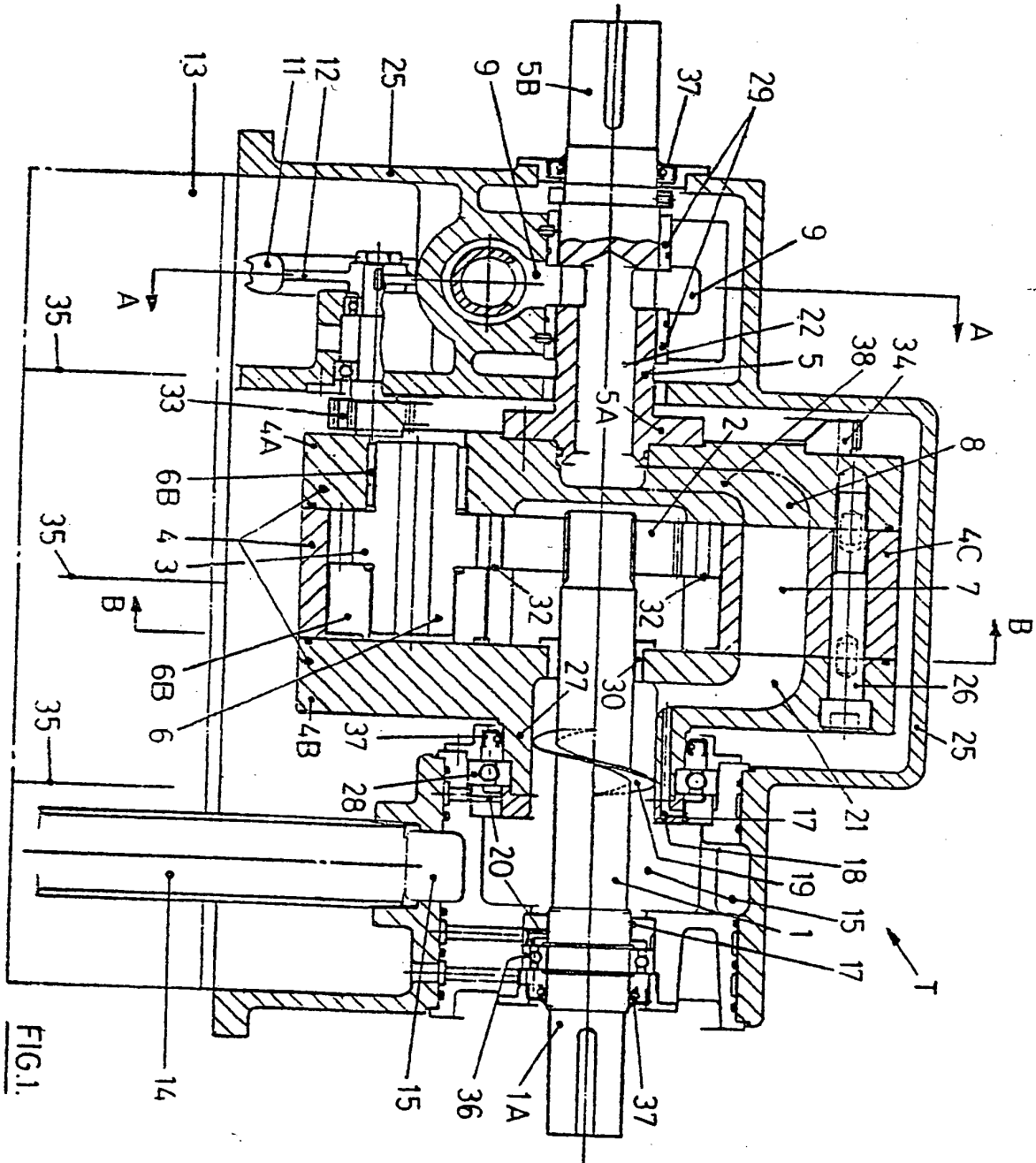


FIG. 1.

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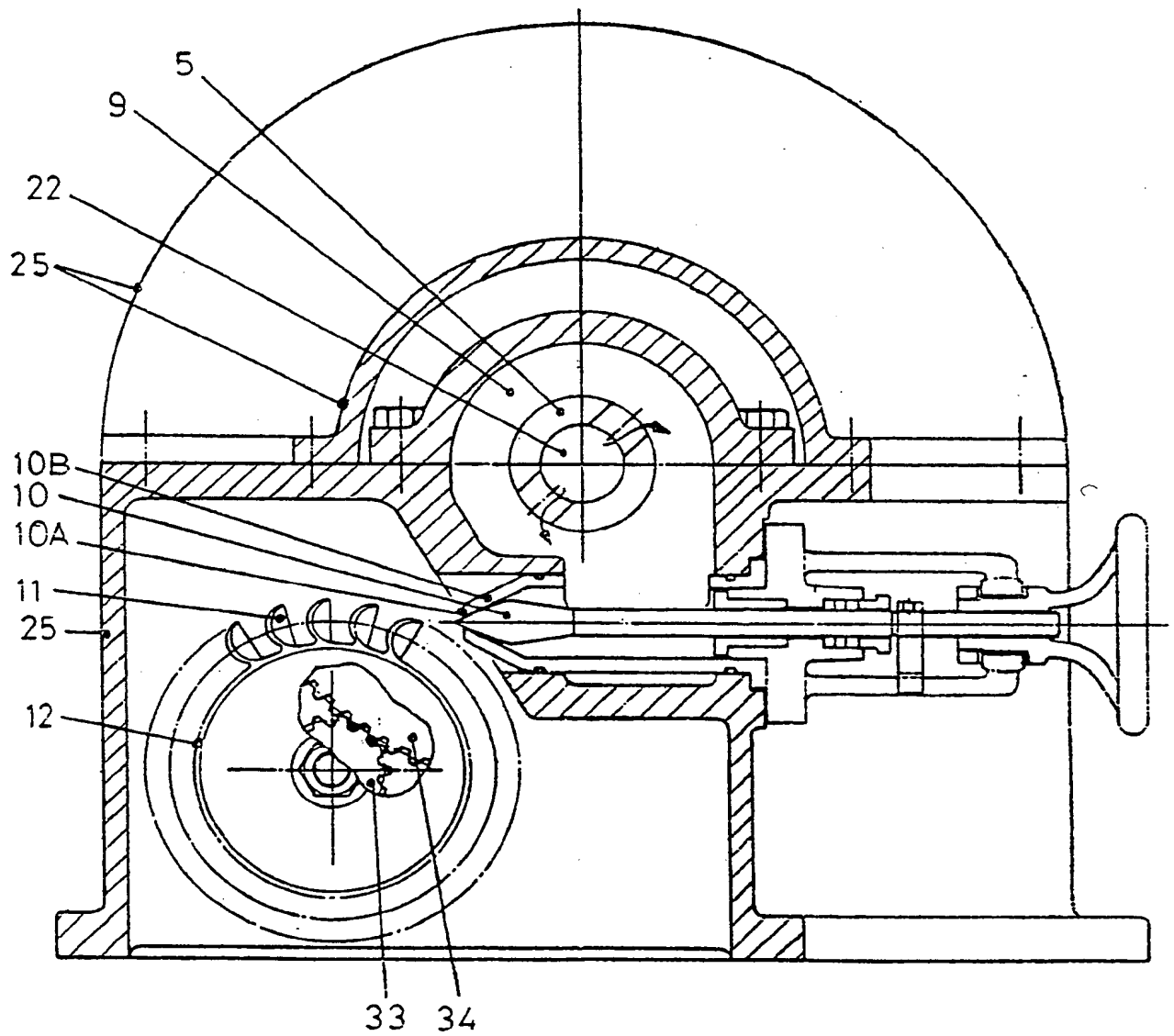


FIG. 2.

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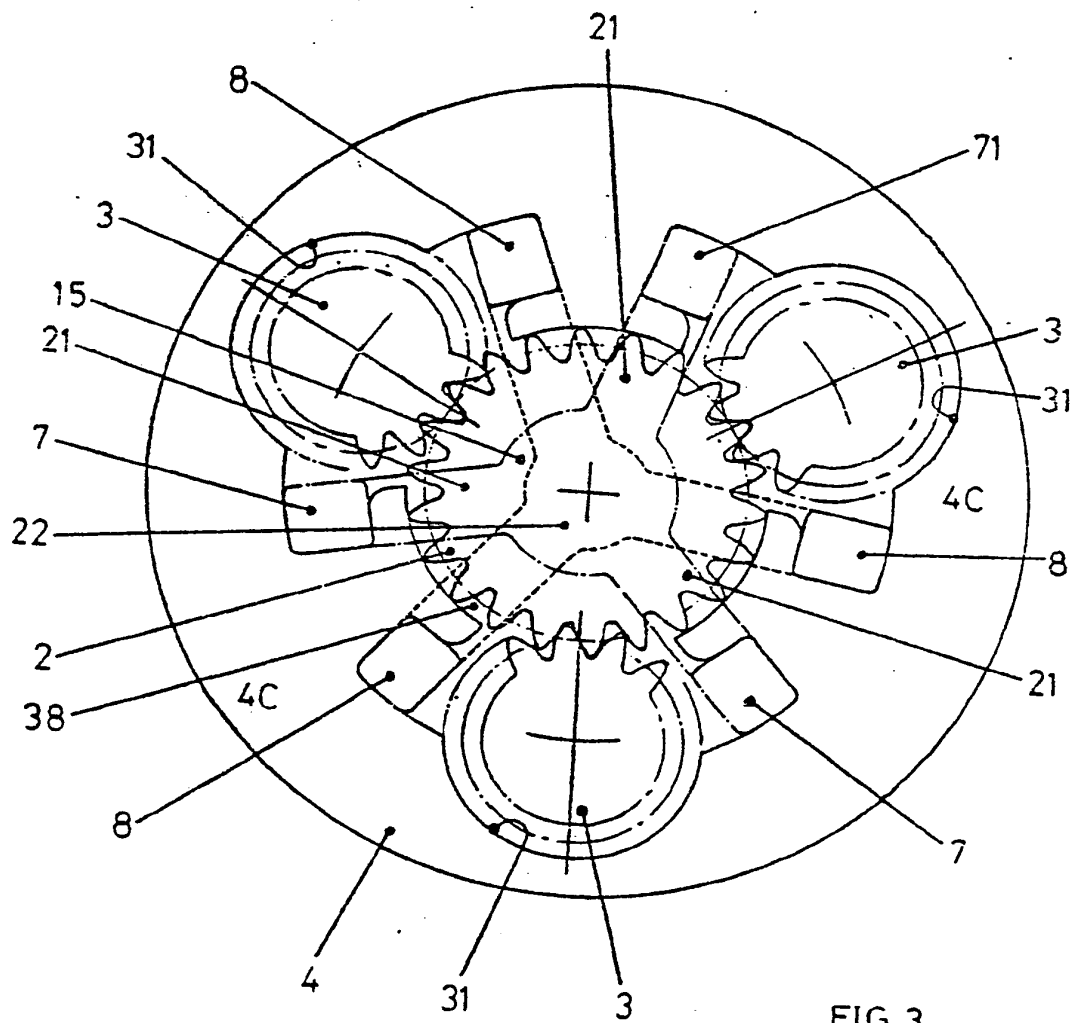


FIG. 3.

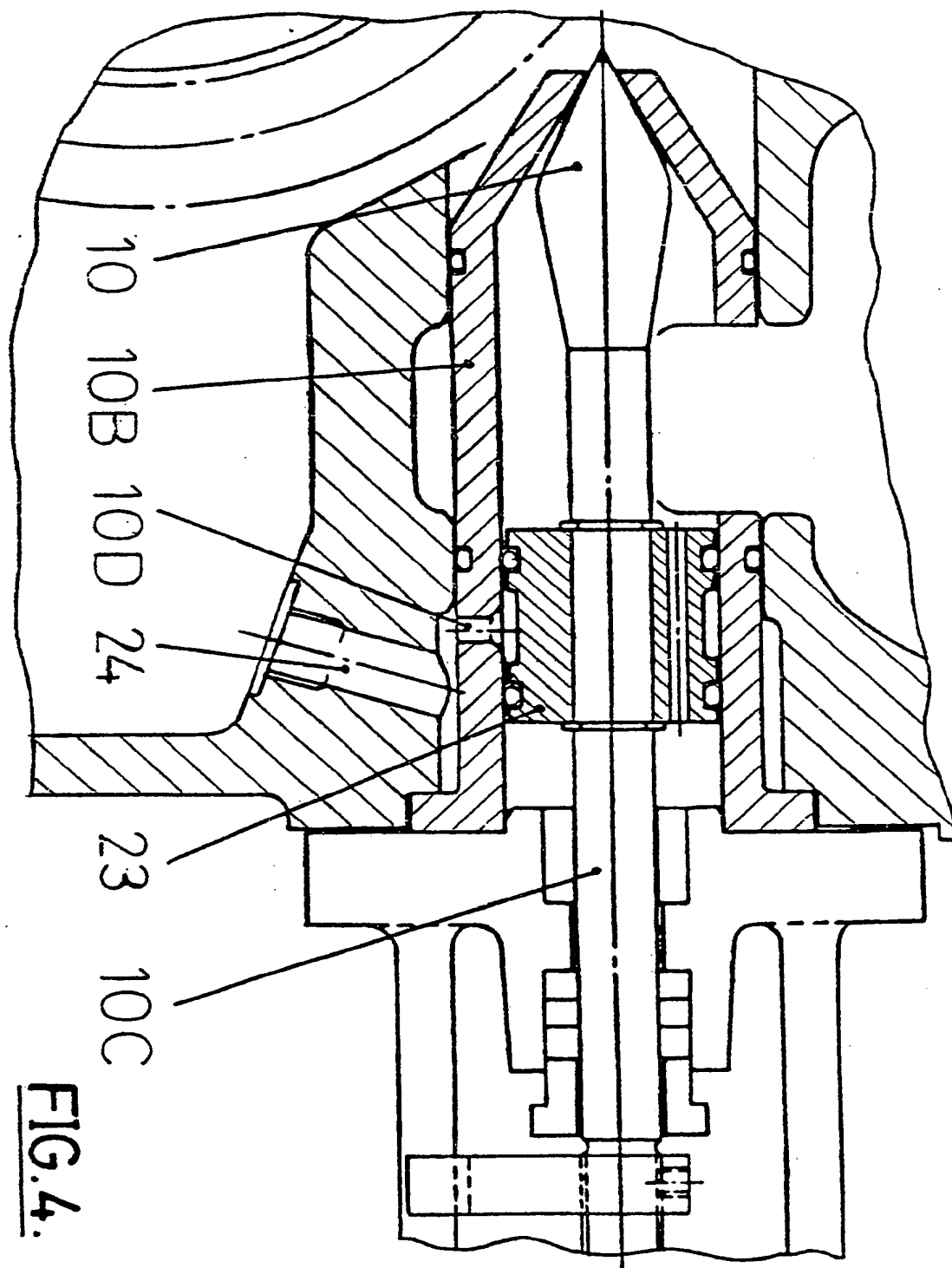


FIG.4.

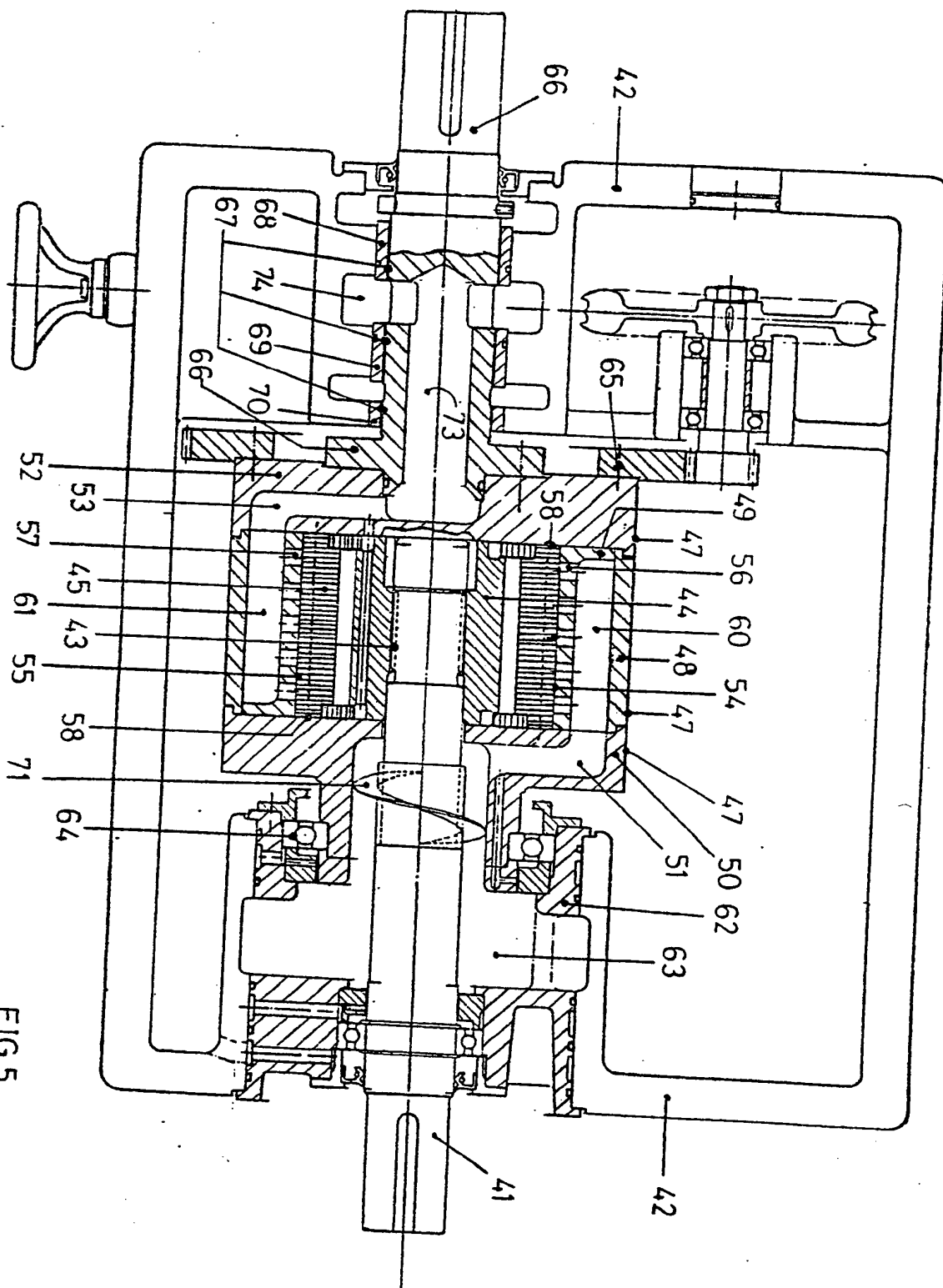


FIG. 5.

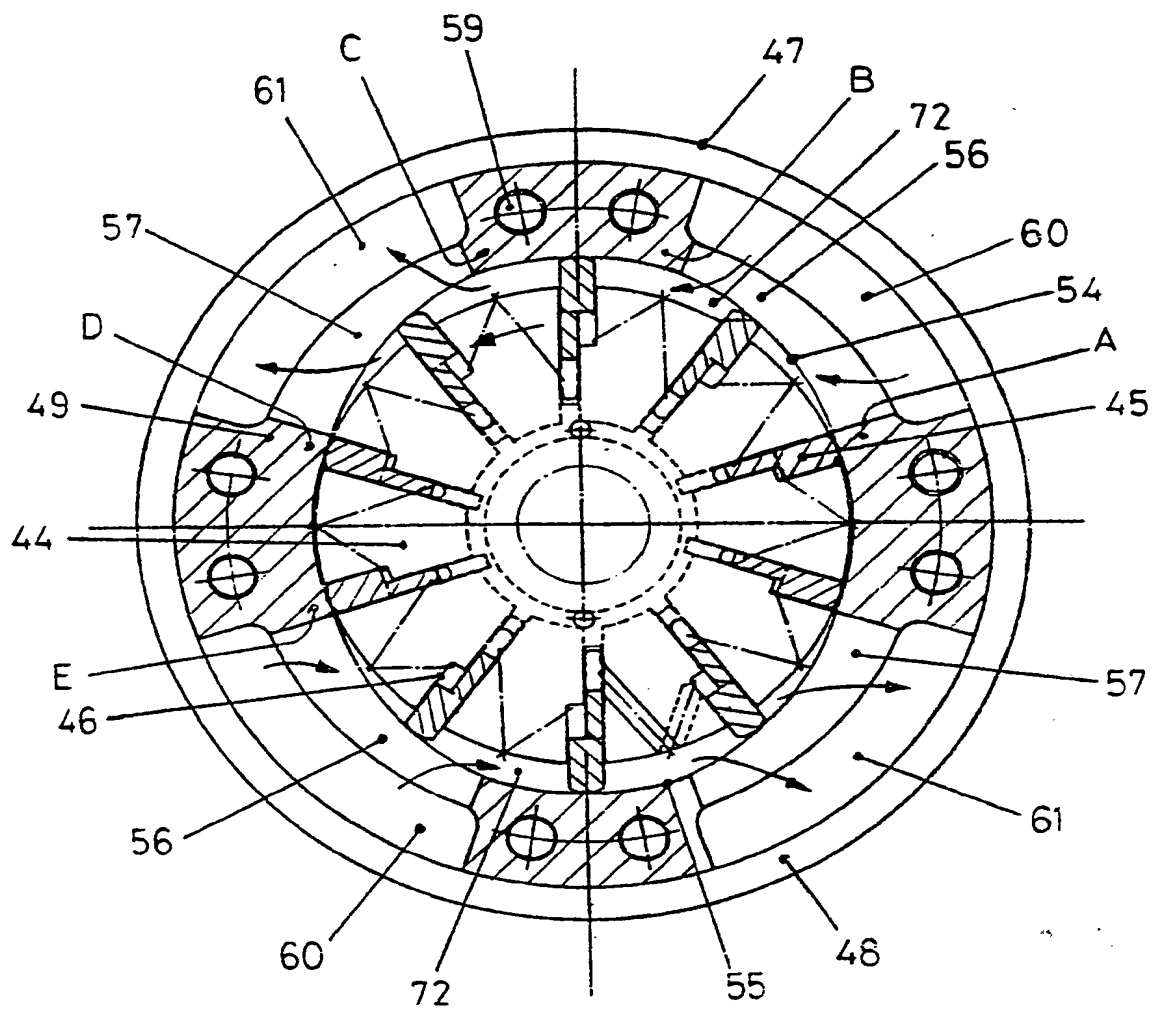


FIG. 6.

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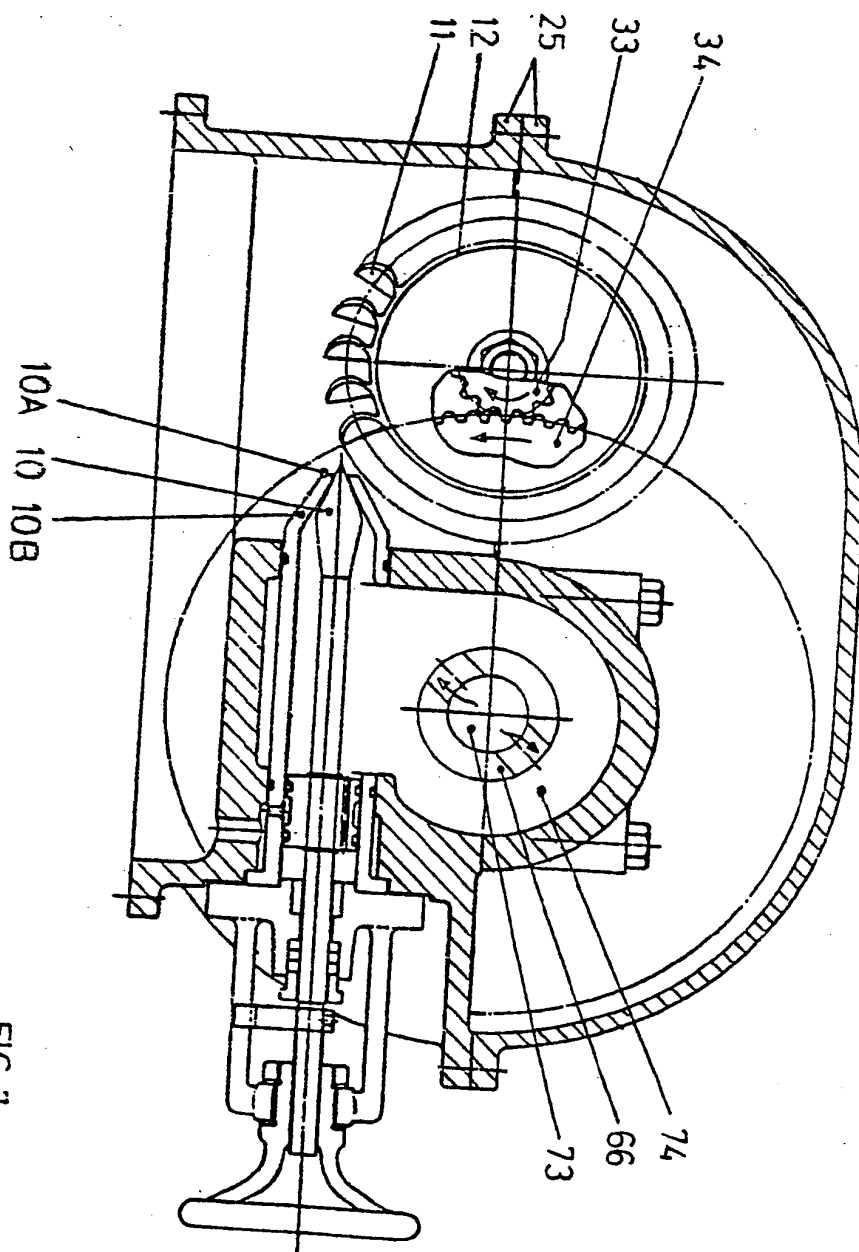


FIG. 7.

SPECIFICATION

Variable speed transmission

- 5 The present invention relates to a variable speed transmission including fluid pumping means.

- Variable speed transmissions are known wherein an input is connected to an output via an epicyclic gear or other mechanical differential type gear, and additionally a fluid power system is connected between the epicyclic or differential gear and the output (or alternatively the input). In one particular example (see German Patent Specification OLS 2902893), a pump of the fluid power system is driven by a slippage element of a differential gear, i.e. by the orbiting planet carriage of the gear and supplies pressure fluid to a fluid motor drivingly coupled to the output shaft: this enables slippage power to be regained when the transmission is operating in a speed reducing mode, i.e. with the planet carrier orbiting. The present applicant's European Patent Application No. 82304449.0 describes a further improved form of variable speed transmission of this type.

- It is an object of the present invention to provide an efficient variable speed transmission including fluid power means but which is of simplified construction.

- According to the present invention there is provided a variable speed transmission comprising a drive shaft system including a rotary input shaft and a rotary output shaft, fluid pumping means of the positive displacement type constituting part of said drive shaft system, said pumping means including first and second reaction elements for creating a fluid pumping effect, the first reaction elements being driven by one of said input and output shafts while the second reaction element is adapted for movement adjustment whereby the pumping effect can be varied even when said one rotary shaft driving the first reaction element rotates with uniform speed, a fluid inlet to the pumping means, and a fluid discharge from the pumping means. Preferably said second reaction element is drivingly connected to the other of said input and output shafts.

- In a preferred embodiment, said pumping means embodies a casing which is coupled, or is drivingly connected (e.g. by gearing) to, and rotates with, the rotary output shaft; and a rotor or rotors housed within said casing, these rotors being coupled, or drivingly connected to the rotary input shaft. The transmission may alternatively comprise a pumping means embodying a casing coupled to, and rotating with the input shaft, and a rotor or rotors housed within this casing coupled, or drivingly connected to the output shaft, i.e. the inverse of the above described arrange-

ment.

- Preferably the amount of fluid discharged by the pumping means is controlled by means of a throttle valve, and preferably this valve is a spear valve, the jet from which is preferably arranged to drive a fluid turbine which is drivingly connected to the output shaft.

- In one of several preferred embodiments, the fluid pumping means comprises a gear pump wherein the pump gears form an input sun gear and planet gears, the planet gears being housed within the rotating pump casing connected to the output shaft. This rotating casing additionally constitutes the planet carrier.

- In a second preferred embodiment the fluid pumping means comprises a sliding vane pump wherein the rotor carrying the sliding vanes is driven by the input shaft, and the casing, within which this rotor rotates and which is internally lobed, is connected to the output shaft.

- The variable speed transmission according to the present invention enables a substantial reduction in the number of operating parts in comparison with prior art transmissions incorporating hydrostatic elements, particularly due to the fact that the rotating positive displacement pumping means provides the dual function of effectively transmitting torque in a mechanical mode from the input shaft to the output shaft when the input/output speeds are uniform, and of absorbing the slip work done in the form of hydraulic energy in a speed reduction mode, which energy is recoverable in a hydraulic turbine or hydraulic motor drivingly connected to the output shaft.

- Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings in which:

- Figure 1* shows a cross-sectional side view of a variable speed transmission according to the present invention;

- Figure 2* shows a sectional end of the transmission of *Fig. 1* through section A-A;

- Figure 3* shows a further sectional end view of the transmission of *Fig. 1* through section B-B; and

- Figure 4* shows a view of a portion of *Fig. 2* but including a modification.

- Figure 5* shows a cross-sectional plan view of a variable speed transmission through section X-X in *Fig. 6* according to another embodiment of the present invention;

- Figure 6* shows a sectional view through section Z-Z through the pumping means of *Fig. 5*; and

- Figure 7* shows an end view looking on cross-section Y-Y of *Fig. 5*.

- Referring to *Figs. 1-3*, a variable speed transmission T is provided for use in transmitting power between an input member (not shown) and an output member (not shown).

- The transmission T is particularly intended for

use in drives where the maximum output speed is very nearly equal to the input speed, and the transmission can find wide application in drives for rotodynamic pumps, fans and compressors, in which the output torque is substantially proportional to the square of the output speed, and for positive displacement pumps and conveyors, in which the output torque is substantially constant.

- 10 The transmission T includes an input shaft 1, housed in a fixed casing 25, and having a splined or grooved end 1A for coupling to the input member, and the shaft 1 carries a sun gear 2 driving a plurality of planet gears 3
- 15 which are housed in and supported by a close fitting rotatable casing 4. The rotatable casing 4 comprises disc end walls 4A, 4B secured together by set screws 26, and an annular wall part 4C spacing walls 4A, 4B; and the planet wheels 3 have axial spindles 6 rotating in hydrostatic bushes 6B in the walls 4A, 4C. The wall 4A is secured to a flange 5A of an output shaft 5 whose outer end 5B is adapted for coupling to the output member. The wall
- 20 4B has a cylindrical portion 27 mounted within ball bearing 28 while the shaft 5 is journalised in bearing sleeves 29 to enable rotary support of the casing/planet carrier 4; shaft 1 entering casing 4 via sleeved bore 30.
- 30 The planet gears 3 are located in part cylindrical housings 31 in the wall part 4C (see especially Fig. 3), which housing 31 serve as pumping chambers, and the sun gear 2 and planet gears 3 in addition to providing a mechanical drive also serve as hydrostatic gear pumps 32. Hydraulic fluid, preferably oil, for the gear pumps 32 is taken from a sump 13, and fluid delivery to the pumps 32 is via inlet conduit 14 to an inlet manifold 15
- 40 located in the casing 25 and cylindrical portion 27, then via ducts 31 in wall 4B to ports 7 in wall part 4C (Fig. 3). The radial ducts 21 in rotating wall 4B have an 'impeller' function to assist inlet fluid flow to the gear pumps 32.
- 45 Pressurised fluid is discharged via ports 8 and ducts 38 in wall 4A to an axial duct 22 in shaft 5 which duct 22 leads to an outlet manifold 9 in casing 25. The inlet port 7 is located adjacent to the meshing zone of the
- 50 gears where the respective teeth are receding from each other, while the outlet port 8 is located adjacent where the teeth are approaching each other.
- In the embodiment, the high pressure fluid
- 55 from gear pumps 32 is directed to impinge on the buckets 11 of an impulse turbine 12, fluid flow from the outlet manifold 9 to the turbine being regulated by a spear valve 10 (Fig. 2) in a turbine nozzle 10A, while fluid discharge
- 60 from the turbine 12 falls freely into the sump 13. The power from turbine 12 is fed to the output shaft 5 and to this end a pinion 33 coupled to the turbine 12 drives a gear wheel 34 concentric with the shaft 5 and secured to
- 65 the casing 4 so as to drive the shaft 5.

Adjacent stationary and rotating parts of the inlet and outlet manifold have close clearances to minimise leakage.

The transmission T includes or may include the following further design features.

- (a) Fluid cooling means (e.g. tubes) in the sump 13.
- (b) Shaft 1 includes an axial impeller 19 for inlet pressure boosting.
- 75 (c) Sealing fluid (oil) to prevent air being drawn into the inlet manifold clearances 17 is taken from a point 18 as the discharge or axial impeller 19 and led to clearances 17 via ducts 20. Alternatively a small separate sealing pump may be provided.
- (d) Baffles 35 are located in sump 13 for regularised flow in the inlet duct 14, and to assist in deaeration of the hydraulic fluid.
- (e) Shaft 1 is mounted in ball bearing 36 and
- 85 fluid seals 37 are located where appropriate.
- The transmission T operates as follows: at start up rotation of the input shaft 1 causes the planet gears 3 to rotate and consequently the gear pumps 32 operate to cause working
- 90 fluid to be drawn in via port 7, pumped around housing 31 to the discharge port 8, and with the spear valve 10 at least partially open the pressurised fluid passes to the outlet manifold 9 whence it is discharged onto the
- 95 turbine buckets 11 via the nozzle 10: the turbine 12 therefore rotates, causing the casing 4 and the output shaft 5 to rotate albeit at a low speed initially. The rotating casing 4 will reduce the pumping effect of pumps 32
- 100 by virtue of the reduction of rotation of planets 3; and at full speed operation the spear valve 10 will be closed, effectively locking the planets 3, and the casing 4 (and the shaft 5) rotates substantially in unison with the
- 105 input shaft 1 but with a small slippage reduction due to clearance leakage. When the spear valve 10 is opened the planet gears can rotate about their axes and, acting with the sun gear pass high pressure fluid (preferably hydraulic oil) to the impulse turbine: in this mode there is speed reduction. Thus the arrangement
- 110 serves to recover a substantial proportion of the slippage power which is generated through the gear pumps 32 when the output speed is less than the input speed.
- In the modification shown in Fig. 4, the fluid quantity which may be discharged by pumps 32 is increased by the incorporation
- 120 on the needle valve spindle 10C of an additional sleeve valve member 23, which is axially moveable with the spindle 10C. This sleeve valve 23 is positioned on spindle 10C such that bypass ports 10D in needle valve body 10B remain closed until the needle valve
- 125 spindle 10C and needle valve 10 are moved to the right to the fully open position. Further movement to the right of the valve spindle 10C causes the sleeve valve member 23 to uncover bypass ports 10D, permitting additional fluid to pass direct to the sump 13 via

conduit 24, without impinging on the turbine buckets 11. This arrangement thus allows higher maximum rotational speeds in the planet gears 3, thereby permitting greater slips and lower transmission output speed on shafts 5, without the need for increasing the size of buckets 11 excessively.

The high pressure oil bypassing the impulse turbine 12 and passing directly to the sump 13 can be used to provide the power fluid for a jet pump booster (not shown) preferably arranged in the sump at the suction of the transmission, to provide the increased inlet pressure required by the rotating gear pumps 32 at large slips to avoid cavitation, when a separate mechanically driven booster pump is not provided for feeding oil to the transmission.

The relationship between the speed of the jet from the spear valve, 10, and the peripheral speed of the impulse turbine buckets, 11, is such as to give good efficiency of slip power recovery, especially at the higher power region of the operating range of the drive.

Referring now to the embodiment shown in Figs. 5 to 7, a variable speed transmission includes an input shaft 41, housed in a fixed casing 42, and having a splined or keyed end 43 for coupling to a sliding vane pump rotor 44. This rotor is generally of cylindrical shape with a series of ten stepped radial slots 46 machined into it. The pump rotor 44 carries ten vanes 45, also of a stepped cross-section, which are a close sliding fit in the corresponding slots 46. Pump rotor 44 is housed in, and supported by, a rotatable casing 47, which comprises a cylindrical outer pressure shell 48, an internally lobed liner 49, an end cover 50 containing inlet ducts 51, and an end cover 52 containing outlet duct 53. The liner 49 is provided with a non cylindrical bore with two concave lobed surfaces 54, and 55, symmetrically disposed about the axis of rotation. The liner is radially slotted to provide inlet ports 56 and outlet ports 57. The axial length of the ten sliding vanes 45, is determined such that fine axial clearances 58 are maintained at all times between the ends of vanes 45 and the internal faces of the end covers 50 and 52.

The liner 49 is fitted with eight trapped holes 59 at each end, and the end covers 50 and 52 are bolted to the liner by socket screws (not shown) which are fitted to these tapped holes. The liner 49 has two external axial recesses 60 cast or machined over all or most of the full length of the outer surface to form an inlet duct for the pump, and two similar external axial recesses 61 which form an outlet duct from the pump, when the liner is contained within the outer pressure shell 48.

The fixed casing 42 is fitted with a fixed inlet liner 62, the interior manifold 63 of which communicates with the oil in the casing sump by a means (not shown) which is of

similar form to inlet conduit 14 as described in the first embodiment (Fig. 1) of this invention.

The rotating pump casing 47 is mounted at its inlet end by a bearing 64 fitted within fixed casing liner 62. This bearing permits the pump casing 47 to rotate freely. The pump casing 47 is bolted at its discharge end to a hollow flanged output shaft 66 by bolts 65, fitted in to end cover 52, which rotates freely with a fine (restriction) clearance 67 within stationary sleeves 68, 69 and 70, which are a tight sealed fit in the fixed casing 42. The restriction clearance 67 mitigate against escape of pressurised fluid via the bore of shaft 66, and end chambers 74A, 74B are provided to catch any leakage fluid.

Rotation of the input shaft 41 of the transmission at a higher speed than the output shaft 66 causes the pump rotor 44 to rotate relative to the casing 47. This causes hydraulic fluid, preferably oil, to be drawn from the sump located underneath the casing 42 into the manifold 63, whence it flows with an increase in pressure via axial impeller (inducer) 71 and radial ducts 51 to inlet ducts 60, and thence via inlet ports 56 to the pump working chambers 72 between the sliding vanes 45. High pressure fluid is discharged from the interior of the pump via outlet ports 57, to outlet ducts 61 and 53, and thence to the bore 73 of output shaft 66. This duct 73 leads to an outlet manifold 74 in casing 42.

The pressure energy in the high pressure fluid is converted to velocity energy by means of the spear valve 10, of similar construction to the described in the first embodiment. The volume of fluid permitted to flow through the valve nozzle 10A to the bucket of the energy recovery turbine buckets 11 is controlled by the position of spear valve 10. As in the previous embodiment, fluid discharge from the turbine 12 falls freely to the sump, and the power from the turbine is fed to the output shaft 66 via pinion 33 and gear wheel 34, the latter being mounted on, and concentric with the rotating casing 47 which is directly connected to the output shaft.

In this embodiment, further design features may be included, as described previously for the first embodiment, viz:

- fluid cooling means in the sump.
- sealing fluid to prevent air being drawn into fine clearances.
- sump baffles to assist aeration.
- spear valve bypass arrangements.

In operation, this embodiment operates in the same basic functional way as in the embodiment incorporating the gear pumps, the latter being replaced by the sliding vane pump. Specifically, when the spear valve 10 is closed, a fluid lock occurs in the vaned pump and the pump effectively acts in a mechanical mode to transmit input rotation to the output shaft 66.

Both embodiments described are suitable for a range of power outputs between 50 kW and 1000 kW, and speeds of between 600 RPM and 3600 RPM.

- 5 Variable speed transmissions according to the two embodiments of the invention above described have substantial advantages over conventional hydraulic couplings in that they are both more compact and enable a significant proportion of the slip to be recovered when the output speed is substantially less than the input speed. They are also more efficient over the entire speed than a hydrokinetic torque converter of the Föttinger type.
- 15 Furthermore, they are economic to manufacture and compare favourably on a cost basis with all alternative forms of variable speed drive. For continuous operation over a wide speed range it is preferable that the power recovery turbine is incorporated to minimise energy losses. For other applications in which over most of the operating life the output speed is required to be very nearly the same as the input speed and operation at low
- 20 output speeds is only required at start up or other exceptional circumstances then the drive systems as described above may operate with direct discharge of the fluid from the rotating positive displacement pumps via a valve back to the sump. Such a system has the disadvantage that the slip power is not recovered but this disadvantage is less important for applications where continuous operation at low output speeds is not required, and results in an
- 25 extremely compact and inexpensive variable speed transmission particularly suitable for low speed high torque applications. A fluid drive motor other than an impulse turbine could also be used to recover slip power.
- 30 Further modifications are of course possible in the transmission. For example, different types of positive displacement pumps could be used other than the above described gear and vane pumps; for example, pumps of the
- 35 screw, radial piston or axial piston types could be used.

CLAIMS

1. A variable speed transmission comprising a drive shaft system including a rotary input shaft and a rotary output shaft, fluid pumping means of the positive displacement type constituting part of said drive shaft system, said pumping means including first and second reaction elements for creating a fluid pumping effect, the first reaction elements being driven by one of said input and output shafts while the second reaction element is adapted for movement adjustment whereby the pumping effect can be varied even when said one rotary shaft driving the first reaction element rotates with uniform speed, a fluid inlet to the pumping means, and a fluid discharge from the pumping means.
2. A variable speed transmission as

claimed in claim 1, wherein said second reaction element is drivingly connected to the other of said input and output shafts.

3. A variable speed transmission as claimed in claims 1 or 2 wherein means are provided to close the fluid discharge from the pumping means whereby the first and second reaction elements are fluidly locked to permit the rotary shafts to rotate at substantially the same speed.

4. A variable speed transmission as claimed in any one of the preceding claims, wherein said pumping means comprises rotor means drivingly coupled to said one rotary shaft and a pump casing housing said rotor means.

5. A variable speed transmission as claimed in claim 4, wherein the pump casing is adapted for rotation so as to rotate with said other one of the rotary shafts.

6. A variable speed transmission as claimed in claim 4, wherein the pumping means comprises a gear pump, said gear pump comprising a sun gear constituting one of said reaction elements and a planet gear meshing with said sun gear and constituting the other of said reaction elements, the planet gear being carried by a planet carrier.

7. A variable speed transmission as claimed in claim 6 and additionally as claimed in claim 5, wherein the planet carrier comprises at least part of said rotary pump casing.

8. A variable speed transmission as claimed in claim 4, wherein the pumping means is of the vane or lobed type, and the rotary pump casing constitutes said second reaction element.

9. A variable speed transmission as claimed in claim 8, wherein the pumping means is a sliding vane pump, said rotor means comprising a rotor carrying sliding vane which engages with the internal periphery of the rotary casing, said sliding vanes constituting said first reaction element and the rotary casing being of internally lobed form.

10. A variable speed transmission as claimed in claim 3, wherein the closure means for the pumped fluid discharge comprises a throttle valve.

11. A variable speed transmission as claimed in claim 10, wherein the throttle valve comprises a spear valve.

12. A variable speed transmission as claimed in claim 10 or 11, including a fluid motor driven by fluid discharged from the pumping means via said fluid discharge, said fluid motor being drivingly connected to said other one of the rotary shafts.

13. A variable speed transmission as claimed in claim 12, wherein the fluid motor comprises a turbine.

14. A variable speed transmission as claimed in claim 4, wherein fluid input and output manifolds surround the input and output shafts respectively, and the manifolds are

fluidly connected to fluid chambers within the casing wall by ducting provided within the casing wall, said chambers opening into the interior of the casing.

5 15. A variable speed transmission as claimed in any one of the preceding claims, wherein the fluid discharge from the pumping means comprises an axially extending internal passage within one of said rotary shafts.

10 16. A variable speed transmission as claimed in claim 15 when dependent on claim 14, wherein said internal passage is located in the output shaft, and fluidly communicates with said output manifold via a radial duct in the output shaft, and annular seal means surround the shaft on either side of said radial duct to mitigate against escape of pressure fluid via the shaft bore.

20 17. A variable speed transmission as claimed in claim 16, wherein the annular seal means comprises elongate sleeves surrounding the rotary shaft and defining elongate restriction passageways with the shaft, said passageway opening into end chamber remote from said radial duct.

25 18. A variable speed transmission as claimed in claim 14, wherein said pumping means includes an inducer located in said input manifold.

30 19. A variable speed transmission as claimed in claims 12 or 13 wherein means are provided to cause at least a portion of the pressurised fluid discharged by the pump means to by-pass the fluid motor.

35 20. A variable speed transmission as claimed in claim 19 wherein said fluid by-pass means are embodied in the throttle valve.

CLAIMS

40 1. A variable speed transmission comprising a drive shaft system including a rotary input shaft and a rotary output shaft, fluid pumping means of the positive displacement constituting part of said drive shaft system, 45 said pumping means including first and second reaction elements for creating a fluid pumping effect, the first reaction elements being driven by said input shaft while the second reaction element is adapted for movement adjustment whereby the pumping effect can be varied even when said input shaft driving the first reaction element rotates with uniform speed, a fluid inlet to the pumping means, and a fluid discharge from the pump- 55 ing means, a fluid motor receiving pressure fluid discharged from said pumping means and for drivingly connected to said output shaft, valve means for regulating the flow of pressure fluid from the pumping means to the fluid motor, and means drivingly connecting said fluid motor with said second reaction element of the pumping means whereby the pumping effect is varied.

65 2. A variable speed transmission as claimed in claim 1, wherein said fluid motor

comprises a turbine.

3. A variable speed transmission as claimed in claim 1 or 2, wherein the valve means comprises a throttle valve.

70 4. A variable speed transmission as claimed in claim 3, wherein the throttle valve comprises a spear valve.

5. A variable speed transmission as claimed in any one of the preceding claims, 75 wherein said second reaction element is drivingly connected to the output shaft.

6. A variable speed transmission as claimed in any one of the preceding claims, wherein said pumping means comprises rotor means drivingly coupled to said input shaft and a pump casing housing said rotor means.

80 7. A variable speed transmission as claimed in claim 6, wherein the pump casing is adapted for rotation said pump casing being driven by said output shaft.

8. A variable speed transmission as claimed in claim 6, wherein the pumping means comprises a gear pump, said gear pump comprising a sun gear constituting one 90 of said reaction elements and a planet gear meshing with said sun gear and constituting the other of said reaction elements, the planet gear being carried by a planet carrier.

9. A variable speed transmission as 95 claimed in claim 8, and additionally as claimed in claim 7, wherein the planet carrier comprises at least part of said rotary casing.

10. A variable speed transmission as 100 claimed in claim 6, wherein the pumping means is of the vaned or lobed type, and the rotary pump casing constitutes said second reaction element.

11. A variable speed transmission as claimed in claim 10, wherein the pumping 105 means is a sliding vane pump, said rotor means comprising rotor carrying sliding vanes which engage with the internal periphery of the rotary casing, said sliding vanes constituting said first reaction element, the rotary casing being of internal lobed form.

12. A variable speed transmission as claimed in claim 6, wherein fluid input and output manifolds surround the input and out- 115 put shafts respectively, and the manifolds are fluidly connected to fluid chambers within the casing wall by ducting provided within the casing wall, said chambers opening into the interior of the casing.

13. A variable speed transmission as 120 claimed in any one of the preceding claims, wherein the fluid discharge from the pumping means comprises an axially extending internal passage within one of said rotary shafts.

14. A variable speed transmission as 125 claimed in claim 13 when dependent on claim 12, wherein the said internal passage is located in the output shaft, and fluidly communicates with said output manifold via a radial duct in the output shaft, and annular seal means surround the shaft on either side of 130

said radial duct to mitigate against escape of pressure fluid via the shaft bore.

15. A variable speed transmission as claimed in claim 14, wherein the annular seal means comprises elongate sleeves surrounding the rotary shaft and defining elongate restriction passageways with the shaft, said passageways opening into end chamber remote from said radial duct.
- 10 16. A variable speed transmission as claimed in claim 12, wherein said pumping means includes an inducer located in said input manifold.
- 15 17. A variable speed transmission as claimed in any one of the preceding claims wherein means are provided to cause at least a portion of the pressurised fluid discharged by the pump means to by-pass the fluid motor.
- 20 18. A variable speed transmission as claimed in claim 17, wherein said fluid by-pass means are embodied in the valve means.
- 25 19. A variable speed transmission substantially as hereinbefore described with reference to and as illustrated in Figs. 1 to 3 or Figs. 1 to 3 as modified by Fig. 4 or in Figs. 5 to 7 of the accompanying drawings.

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